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A STUDY OF WORLD WAR II GERMAN FIRE FATALITIES

by

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SUMMARY OF REPORT

<u>A STUDY OF WORLD WAR II GERMAN FIRE FATALITIES</u>

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1. Seventy-one target cities in Germany were subjected to area incendiary raids during World War II. Eighteen cities were selected from this list for analysis. The criterion for selection was that the city was not raided more than twice or that specific data existed for one raid in cases where the city had been raided several times.

2. Damage, casualty, and raid data were obtained for the cities selected for analysis. From these data gross population, attack parameters, city configuration, and fatality estimates were available.

3. Algorithms were constructed to:

(a) Characterize a theoretical city configuration in terms of zones of combustibility,

(b) Distribute the population over the city,

(c) Distribute the attack over the city,

(d) Estimate the number of initial primary fires and their distribution,

(e) Allocate total reported fatalities to various zones of the city, and

(f) Estimate fatality levels in various fire environments.

4. Application of these algorithms to the eighteen German target cities produced estimates of fatality levels. Firestorm fatalities were estimated to vary between 4% and 20% of the population-at-hazard. Group fire fatalities were estimated to include up to 4% of the population-at-hazard.

Limitations on extension of these estimates to the nuclear case and to U. S. cities are discussed.

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ABSTRACT

Ranges for estimated fire fatalities are developed for firestorms and group fires initiated by conventional weapons in German cities during World War II. Firestorm fatalities are estimated to vary between 4% and 20% of the population-at-hazard. Group fire fatalities are estimated to include up to 4% of the population-at-hazard.

Limitations on extension of these estimates to the nuclear case and to U. S. cities are discussed.

A STUDY OF WORLD WAR II GERMAN FIRE FATALITIES

1.0 Introduction

1.1 A basis is needed for predicting fatalities likely to result from fires initiated by a nuclear attack on the United States. Present predictions are based largely on "rules-of-thumb." A study of historical data provides a realistic starting point for developing fire fatality estimating procedures of this kind.

1.2 In this study, German World War II experience was investigated and estimates made of the level of fatalities associated with firestorms and group fires initiated by conventional incendiary and high-explosive weapons. Extrapolations from this data to fire fatalities likely to result from nuclear weapon attacks against the United States must be recognized as very uncertain because of significant differences in weapon effects, methods of attack, and building construction. It is intended that future work will examine the experiences of Japan in World War II and various natural disasters in the U. S. and abroad. Such extensions should indicate the ranges of estimating factors to be expected under conditions associated with conventional warfare and natural disasters. This data will provide some insight into estimating fire fatalities resulting from nuclear attacks on U. S. targets.

D. Within the city, the population distribution influenced the portion of the population placed at hazard by any attack. Superimposed upon the influence of the raw distribution of population were the influences of passive defense measures such as shelter and evacuation. The actual population distributions at the time of the attacks could not be determined. A theoretical distribution model was used for the circular city approximation discussed in C. above. (Also see Refs. 2 and 3.) To estimate the fatality levels, the shelter posture of each target city was assumed to be equivalent to the Hamburg shelter posture reported in Ref. 4. This reduced the maximum population at hazard by 20%, the fraction of the Hamburg population that was sheltered in essentially fireproof construction.

Although the population-at-hazard would be further reduced by evacuation, yielding a still-higher estimate of fatality levels, no quantitative evacuation data was available. Hence, no allowance for evacuation was made in estimating the population-at-hazard.

E. After obtaining a distribution of the population-at-hazard and an estimate of the number of buildings* within the target city, the distribution of weapons over the target and the number of resultant primary fires were estimated. Using the estimated weapon distribution, the total reported fire fatalities could be distributed in proportion to the weapon

*Based on aerial photographs.

density. The distribution of weapons was assumed to be a circular normal distribution. The mean of this distribution was assumed coincident with the "city center," making the weapon probability contours concentric with population density contours given by the theoretical distribution discussed in D. above.

F. The estimated fatality levels, expressed as percentages, were then obtained for various city areas, as ratios of estimated fatalities in the area to estimated population at hazard within the area.

2.2 The detailed analysis involved in A. through F. above is developed in Appendix A, Sections A1 through A6, respectively.

3.0 Fatality Causative Mechanisms

3.1 Very little data is available regarding the causative mechanisms of fire fatalities. Following the firestorm raid on Hamburg, 27/28 July 1943, a group of pathologists under Dr. Helmuth Baniecki performed post-mortems on several corpses recovered from shelters and streets. Results of these post-mortems are reported in Ref. 4. The following conclusions were drawn.

A. For fatalities occurring in shelters, the predominant cause of death was stated to be carbon monoxide inhalation. In some of these cases, the not quite lethal blood concentrations of carboxyl hemoglobin indicated the presence of a condition enhancing CO lethality. Dr. Baniecki and his co-workers concluded that high ambient temperatures produced in the shelters, coupled with probable excited physical behavior could have increased effective lethality of CO inhaled to a degree sufficient to cause death. In only a limited number of cases was evidence present indicating shelter deaths from temperature effects alone.

B. The converse was considered true in street casualties. The predominant cause of death in these cases was considered to be heat or respiratory damage occassioned by hot gases.

3.2 Reference 5 gives four quantitative estimates of partition of fatalities by various causes. These estimates average 84% due to CO and hot gas inhalation and 16% due to non-fire mechanical injury. These are percentages of the total reported fatalities.

3.3 Application of such estimates of causative mechanisms or percentages to the group fire cases is highly uncertain, since all pathology data was obtained by analysis of firestorm victims. Future work should include studies of records of causes of death for individual fires.

4.0 Results

4.1 The mean fatality level inside firestorm areas was estimated to be 15% of the population-at-hazard. For the areas outside the firestorm area where fires were set by the same raid, the mean fatality level was estimated as 3% of the population-at-hazard.

4.2 For the target cities that sustained only group fires, the mean fatality level was estimated as 1.4% inside areas greater than 40%

built-up. For areas less than 40% built-up, the mean fatality level was much less than 1%.

4.3 In firestorm cases, the mean fatality level was estimated as 4.0 deaths per initial primary fire. For group fire cases, this mean level was estimated as less than one death per initial primary fire.

4.4 The individual cases studied are shown in Table I. Procedures used to develop this data are shown in Appendix A.

5.0 Conclusions

5.1 The disparity between the mean fatality levels for firestorms and group fires illustrates the necessity of predicting the occurrence of firestorms. This study indicates that fatalities may increase by an order of magnitude if a firestorm develops in any given area.

5.2 An indicator of fire severity in Germany was the estimated ratio of total buildings in an area to buildings initially ignited in the area. Both the factors of deaths per initial primary fire and fatality fraction increased sharply when this ratio fell to about 5:1. Fire spread alone may account for this increase. Research should be carried out (for example) to determine whether the rate of liberation of toxic combustion products increases sharply with increasing fire density and hence materially decreases the time available for remedial action.

5.3 The policy of remaining in shelter under all circumstances must be further investigated. During the time required for a firestorm to

TABLE 1

Results

A. Firestorm Cases:

City	Estimated fire fatalities (total)	Estimated fatality level inside firestorm area (fraction of pop. at hazard)	Estimated fatality level outside firestorm area (fraction of pop. at hazard)	Estimated deaths per initial primary fires inside firestorm area
Darmstadt	8,100[1]	0.12	0.04	2.0
Dresden	135,000[2]	0.18	0.02	9.7
Hamburg	41,800[1]	0.19	0.03	3.1
Heilbronn	5,629[3]	0.17	0.04	4.3
Kassel	8,659[1]	0.08	0.02	1.1
(Mean Values)		0.148	0.03	4.0

[1] Ref. 5

[2] Ref. 6

[3] Ref. 4

B. Group Fire Cases:

City	Estimated fire fatalities (total) (Ref. 4)	Estimated fatality level inside area >40% built-up (fraction of pop. at hazard)	Estimated fatality level outside area >40% built-up (fraction of pop. at hazard)	Estimated deaths per initial primary fire inside area >40% built-up
Aachen	2,054	0.01	0.004	1.2
Freiberg	2,035	0.03	0.01	2.0
Friedrichshafen	146	0.02	0.004	0.2
Kaiserslautern	257	0.01	-	0.6
Königsberg	777	0.02	-	0.9
Krefeld	1,056	0.005	-	0.5
Mulheim	209	0.005	-	0.4
Schweinfurt	576	0.02	0.01	2.5
Solingen	2,087	0.02	0.007	1.5
Ulm	504	0.01	0.007	0.3
Witten	51	0.01	-	0.4
Barmen	3,371	0.04	-	0.3
Elberfeld	1,848	0.03	-	0.2
(Mean Values)		0.018	<0.01	0.85

develop, a decision to evacuate could possibly save lives in situations where fireproof shelters are not available. Decision criteria do not exist at this time. Further research must define conditions under which the risk of a high level of fatality in streets during evacuation or remedial movement is preferable to the risk of a possibly higher level of fatality resulting from a "stay-put" policy.

5.4 It must be emphasized that results of this study are estimates only, and that these estimates were made for Germany in World War II. The study of fatalities in other wartime and peacetime fires should be vigorously pursued. While in many nuclear attacks, blast and radiation casualties would overshadow fire casualties, certain types of attacks would result in fire being the principal casualty producer.

5.5 The present study, and future work as now conceived, deals only with gross estimates of fatality due to fire. A method of estimating injuries must precede the development of any useful Fire Casualty Model.

APPENDIX A

DEVELOPMENT OF METHOD OF ANALYSIS

A1. Summary of Area Raid Targets and Bomb Loads:

Table A1

City	Number of main force attacks[1]	Estimated bomb loads in target area per raid (tons)[2] High Explosive	Incendiary
Aachen	2	736	85
Darmstadt	1*	366	500
Dresden	1	1,785	1,190
Freiberg	1	907	133
Friedrichshafen	1	235	205
Hamburg	1*	2,660	2,350
Heilbronn	1	650	290
Kaiserslautern	1	11	109
Kassel	1*	671	822
Königsberg	2	58	152
Krefeld	2	100	102
Mulheim	1	144	72
Schweinfurt	2	56	40
Solingen	2	307	108
Ulm	1	298	347
Witten	1	187	43
Wuppertal/Barmen	2	315	360
Wuppertal/Elberfeld	1	311	362

*Multiple raids occurred--specific data on single raid is available.

[1] Ref. 1

[2] Ref. 5

A2. Target City Configurations:

Table A2

Firestorm Cases

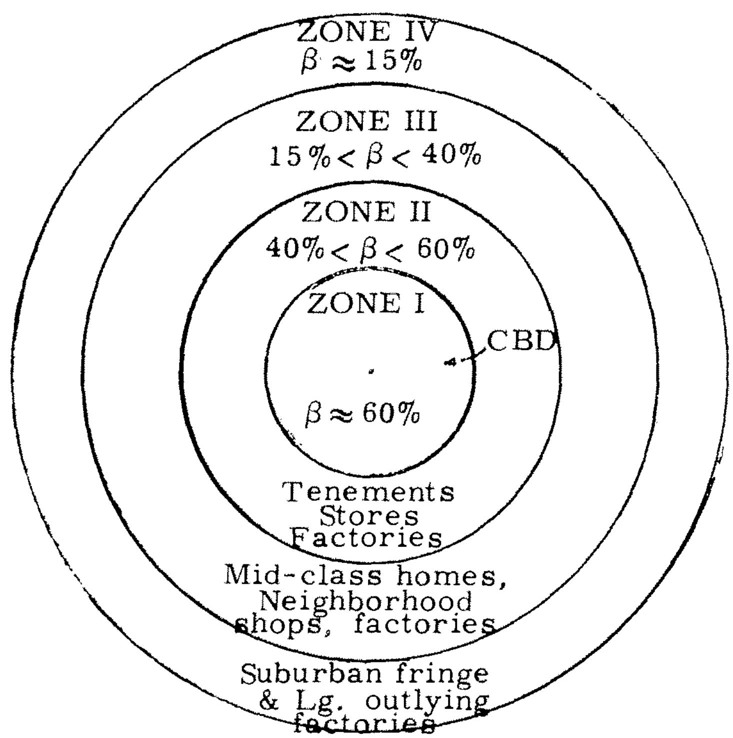
City	Area, $mi.^2$, of firestorm	Radius of equivalent circular representation of firestorm area	Radius including 90% of population (using population distribution discussed in A3)
Darmstadt	1.9	0.78 mi.	1.04 mi.
Dresden	8.0	1.84 mi.	2.11 mi.
Hamburg	5.0	1.45 mi.	2.10 mi.
Heilbronn	0.67	0.46 mi.	0.90 mi.
Kassel	2.5	0.89 mi.	1.50 mi.

Table A3

Group Fire Cases

City	Area, $mi.^2$, built-up $\geq$ 40%	Radius of equivalent circular representation of area built-up $\geq$ 40%	Radius including 90% of population (using population distribution discussed in A3)
Aachen	1.62	0.72 mi.	1.25 mi.
Freiberg	1.08	0.59 mi.	1.05 mi.
Friedrichshafen	0.23	0.27 mi.	0.60 mi.
Kaiserslautern	0.56	0.42 mi.	0.82 mi.
Königsberg	1.29	0.86 mi.	2.10 mi.
Krefeld	2.38	0.87 mi.	1.30 mi.
Mulheim	0.47	0.39 mi.	1.16 mi.
Schweinfurt	0.46	0.38 mi.	0.90 mi.
Solingen	0.54	0.41 mi.	1.16 mi.
Ulm	0.88	0.53 mi.	0.88 mi.
Witten	0.32	0.52 mi.	0.90 mi.
Wuppertal/Barmen	1.78	0.87 mi.	1.50 mi.
Wuppertal/Elberfeld	1.45	0.78 mi.	1.40 mi.

A2.1 The circular approximation used to represent a city is, of course, an artifice. No single geometric configuration or set of configurations would suffice to represent all of the cities studied. Because of historical development patterns of many German cities, a circular representation was considered reasonable. This approximation tends to compress dimensions of a particular area more than a rectangular representation. Such compression is not considered a significant source of error in this study, however. Figure A1 below shows the hypothetical configuration used, after Ewell, Ref. 7.



β = percent of area covered by buildings (built-upness)

Figure A1

A3. Population Distributions and Population at Hazard:

A3.1 The actual distribution of population within the target cities was, of course, unknown. A theoretical distribution was applied, after Refs. 2 and 3. This distribution has been shown in Ref. 3 to fit very closely for several European cities. The basic distribution has the form

$$\rho = \rho_0 e^{-br} \qquad \text{(A3-1)}$$

where ρ = population density at any radius r from the center of the city, and ρ_0 = population density at the city center. The exponent b is a constant for any city, and may be approximated by

$$b = \left(\frac{10^5}{P_m} \right)^{1/3} \qquad \text{(A3-2)}$$

where P_m = total city population. For a city with circular symmetry, the population within any radius r from city center is

$$P(r) = 2\pi\rho_0 \int_0^r x e^{-bx} dx \qquad \text{(A3-3)}$$

or

$$P(r) = \frac{2\pi\rho_0}{b^2} \left[1 - (1 + br)e^{-br} \right] \qquad \text{(A3-4)}$$

The non-circular or general case is

$$P(r) = \frac{\alpha\rho_0}{b^2} \left[1 - (1 + br)e^{-br} \right] , \quad 0 < \alpha \leq 2\pi \qquad \text{(A3-5)}$$

A3.2 Using Eq. (A3-4) or (A3-5), the basic populations present within the circular firestorm areas or the circular areas 40% or more built-up (Tables A2 and A3) could be calculated. Not all members of these basic populations were placed at hazard by a raid, however. For example, within the firestorm area of Hamburg, Earp (Ref. 4) has estimated that about 20% of the population was sheltered in fireproof construction.

Evacuation may have further reduced the population-at-hazard, but, in the absence of data, it was assumed that there was no pre-attack evacuation. Of course, this assumption tends to make the fatality estimates too low.

A3.3 Tables A4 and A5 following show estimated populations at hazard for the cities studied.

A4. Distributions of Bomb Loads:

A4.1 Studies by the Research and Experiments Department of the British Ministry of Home Security have shown that the most accurate analytic representation of bomb hits is an elliptic Gaussian distribution. Based on a very limited number of bomb plots available to this study (Ref. 1), a circular normal distribution was considered an adequate approximation.

Table A4

Populations at Hazard, Firestorm Cases

City	Estimated population at hazard within firestorm area	Estimated population at hazard outside firestorm area
Darmstadt	63,700	34,500
Dresden	708,000	372,000
Hamburg	250,000	135,000
Heilbronn	25,300	44,100
Kassel	119,000	86,000

Table A5

Populations at Hazard, Group Fire Cases

City	Estimated population at hazard within 40% built-up area	Estimated population at hazard in areas <40% built-up
Aachen	62,000	81,000
Freiberg	42,700	56,300
Friedrichshafen	2,900	19,600
Kaiserslautern	23,500	39,500
Königsberg	48,000	298,000
Krefeld	84,000	72,000
Mulheim	22,100	100,900
Schweinfurt	12,700	31,400
Solingen	22,800	103,000
Ulm	33,900	32,600
Witten	15,600	50,100
Wuppertal/Barmen	68,000	112,000
Wuppertal/Elberfeld	59,000	123,000

For the circular area case considered, Ref. 8 gives the following expression for this distribution:

$$P = \int_0^{R_1} g(R)\, dR = 1 - e^{-R_1^2/2} \quad \text{(A4-1)}$$

where P = probability that a point will fall within a radius R_1 of the center of the distribution (assumed located at the origin of the coordinate system), and

$$g(R) = Re^{-R^2/2} \quad \text{(A4-2)}$$

Table 11.10.1, Ref. 8 shows tabulated values of P for R expressed as $R = f(\sigma)$.

A4.2 P_1 given by Eq. (A4-1) or from Ref. 8 may be considered as the fraction of the total bomb load falling within any radius R (in σ-units) of the center of the distribution.

A4.3 Based on Ref. 9, two assumptions were made:

(a) The center of the bomb distribution coincides with the "city center" and hence with the center of the population distribution discussed in Section A3.

(b) Using 3 mi. radial error as the maximum allowed for weapons referred to as "on target", σ may be assumed as 0.75 mi. to 1.0 mi. 0.75 mi. was used in this study.

A4.4 From the basic distribution tabulated in Ref. 8 and the assumptions given above, the fraction of the bomb load reported as on-target which fell within the firestorm area or area greater than 40% built-up (circular approximation) could be determined. Tables A6 and A7 show results of applying this distribution to the firestorm and group fire cases.

A5. Estimation of Primary Fires Resulting from Bomb Distributions:

A5.1 Two principal incendiary weapons were used in area raids. The 4 lb. magnesium unit was used in two versions, normal version and IBX, which contained a small anti-personnel charge. The other principal weapon was the 30 lb. oil bomb. Associated with each of these two weapon types is a probability of fire start. This may be considered as a product of probabilities, or:

$$P_f = \beta \cdot P_\rho \cdot (1 - \epsilon) \cdot I \qquad \text{(A5-1)}$$

where:

- P_f = probability that the weapon will start a fire (incendiary probabilities),
- β = built-upness of the urban area, assumed equivalent to the probability that the weapon will impact on a roof and not in a street or open area,
- P_ρ = probability that the incendiary unit will penetrate the roof of the structure,
- ϵ = probability that a fire defense unit will find and extinguish the incendiary unit before it can ignite structural fuel or furnishings,
- I = the incendiary efficiency of the unit; i.e., the probability that if left unattended inside a structure, the incendiary unit would cause a sustained fire.

Table A6

Bomb Load Distributions - Firestorm Cases

City	Incendiary bomb load dispatched	Estimated tonnage* of incendiaries inside firestorm area	Estimated tonnage* of incendiaries outside firestorm area to 3 mi. from city center or to edge of city
Darmstadt	561	210	90
Dresden	1,190	1,070	120
Hamburg	3,846	736	339
Heilbronn	471	58	92
Kassel	1,745	411	304

Table A7

Bomb Load Distributions - Group Fire Cases

City	Incendiary bomb load dispatched	Estimated tonnage* of incendiaries inside 40% built-up areas	Estimated tonnage* of incendiaries outside 40% built-up area to 3 mi. from city center or to edge of city
Aachen	290	31.4	32.3
Freiberg	251	36.0	47.0
Friedrichshafen	480	21.0	33.0
Kaiserslautern	856	20.0	29.0
Königsberg	172	75.0	75.0
Krefeld	488	50.0	26.0
Mulheim	929	9.0	41.0
Schweinfurt	550	6.0	15.0
Solingen	390	16.0	60.0
Ulm	688	70.0	103.0
Witten	123	6.0	16.0
Wuppertal/Barmen	360	172.0	142.0
Wuppertal/Elberfeld	362	152.0	145.0

*Totals of these last two columns may not equal totals in the last column of Table A1, since use of a 3 mi. allowable error in defining "on-target" bomb loads included some units which fell outside the city built-up areas.

A5.2 Data used in computing P_f for 4-lb. and 30-lb. incendiaries was obtained from British World War II period experiments, Refs. 10 through 15.

A5.3 Incendiary probabilities were combined with bomb-load distributions shown in Tables A6 and A7. Primary fires were estimated for both firestorm and non-firestorm cases. Table A8 shows the numbers of primary fires estimated in firestorm cases, while Table A9 shows similar data for the group fire cases.

A6. <u>Estimates of Fatality Distributions:</u>

A6.1 The total fatalities resulting from the raids studied were reported in Earp (Ref. 4). These fatalities were distributed over the entire city according to the following:

$$\frac{\text{fatalities inside 40\% built-up area}}{\text{fatalities outside 40\% built-up area}} = \frac{\text{weapon density inside 40\% built-up area}}{\text{weapon density outside 40\% built-up area}}$$

for the group fire cases. For the firestorm cases:

$$\frac{\text{fatalities inside firestorm area}}{\text{fatalities outside firestorm area}} = \frac{\text{weapon density inside firestorm area}}{\text{weapon density outside firestorm area}}$$

where the sum of the numerator and denominator on the left of both relations must equal the total fire fatalities reported.

Table A8

Estimated Primary Fires - Firestorm Cases

City	Estimated primary fires inside firestorm area	Estimated primary fires outside firestorm area	Equivalent density inside firestorm area, no./sq. mi.
Darmstadt	3,530	666	1,860
Dresden	13,100	733	1,640
Hamburg	12,400	2,590	2,480
Heilbronn	975	700	1,460
Kassel	6,900	2,250	2,760
		average density =	2,100

Table A9

Estimated Primary Fires - Group Fire Cases

City	Estimated primary fires inside area 40% built-up	Estimated primary fires in portion of city outside area 40% built-up	Equivalent density inside area 40% built-up, no./sq. mi.
Aachen	547	247	337
Freiberg	604	358	560
Friedrichshafen	351	474	1,520
Kaiserslautern	336	222	600
Königsberg	1,250	690	970
Krefeld	839	198	351
Mulheim	151	313	321
Schweinfurt	101	114	220
Solingen	268	457	497
Ulm	1,175	785	1,330
Witten	101	122	316
Wuppertal/Barmen	2,880	1,110	1,620
Wuppertal/Elberfeld	2,540	1,100	1,750
		average density =	875

A6.2 Fatality levels were then computed. Results of this portion of the analysis have been presented earlier in Table 1, Section 4.0.

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